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LETTER

# Collaborative conservation planning: Quantifying the contribution of expert engagement to identify spatial conservation priorities

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**Abstract**
The importance of expert input to spatial conservation prioritization outcomes is poorly understood. We quantified the impacts of refinements made during consultation with experts on spatial conservation prioritization of Christmas Island. There was just 0.57 correlation between the spatial conservation priorities before and after consultation, bottom ranked areas being most sensitive to changes. The inclusion of a landscape condition layer was the most significant individual influence. Changes (addition, removal, modification) to biodiversity layers resulted in a combined 0.2 reduction in correlation between initial and final solutions. Representation of rare species in top ranked areas was much greater after expert consultation; representation of widely distributed species changed relatively little. Our results show how different inputs have notably different impacts on the final plan. Understanding these differences helps plan time and resources for expert consultation.

**KEYWORDS**
biodiversity, Christmas Island, conservation planning, expert elicitation, expert engagement, practitioner engagement, spatial prioritization, species distribution models

## 1 | INTRODUCTION

Systematic conservation planning provides a framework for selecting locations to efficiently achieve conservation goals using ecological and socioeconomic information for a region (Margules & Pressey, 2000). The approach has spurred the development of spatial prioritization tools for identifying priority areas for conservation actions (e.g., Zonation, Marxan) (Kukkala & Moilanen, 2013), and is being increasingly employed with the growing availability of biodiversity data and progress of analytical approaches (McIntosh et al., 2018). Originally conceived in the context of reserve design to achieve more representative networks of protected areas, spatial prioritization is being applied to a broad range of conservation problems, including targeting management actions (Cattarino et al., 2018; Maggini et al., 2013), development planning (Kiesecker, Copeland, Pocewicz, & McKenney, 2010; Whitehead, Kujala, & Wintle, 2017), and biodiversity offset design (Kujala, Whitehead, Morris, & Wintle, 2015).

It is critical to understand the inputs and decisions that may influence the outcomes of spatial conservation prioritization (SCP). In many situations, decisions are made based around a small portion of top ("where to protect?") or bottom ("where to develop?") priority areas. Suboptimal or inaccurate spatial solutions have the potential to result in inefficient conservation resource use or unexpected biodiversity losses. Relative conservation priorities of a focal region may change substantially depending on the prioritization methods that are implemented and the type of biodiversity and spatial data that are used (Kujala, Moilanen, & Gordon, 2018b; Kullberg et al., 2015; Lentini & Wintle, 2015; Rondinini, Wilson, Boitani, Grantham, & Possingham, 2006). Systematic conservation planning also involves a substantial human element, with many parties involved in decisions that are made before, during and after the otherwise technical process of spatial prioritization (Galloway, 2013; Lehtomäki & Moilanen, 2013).

Experts, including practitioners, have a central role in SCP; they provide data, local ecological knowledge (sensu Cook et al., 2014), including verification of species distribution and other environmental data, information on threats, guidance on which biodiversity elements to include and their relative weight, potential land-use scenarios and conservation targets (Galloway, 2013). Collaborating with experts is expected to improve the realism and accuracy of spatial priorities (Galloway, 2013), and collaborating with practitioners in particular is considered a key ingredient in enabling implementation of conservation plans (Knight et al., 2006; Knight et al., 2008). Although collaboration in the development of SCPs appears to be increasing (Sinclair et al., 2018), the contribution of data and decisions that emerge from these collaborations remains poorly quantified. Quantifying the influence of data inputs on the outcomes of SCPs would help planners focus knowledge elicitation toward the most critical information inputs for conservation outcomes and prioritize collaboration toward experts who hold this information.

Here, we document a SCP process on Christmas Island, an external territory of Australia and a site of international conservation significance. The small oceanic island (135 km$^2$) supports seventeen threatened taxa, has a high proportion of endemic species (including birds, reptiles, plants, and invertebrates), provides internationally significant seabird breeding habitat and is unique for its dominance of land crabs (Director of National Parks, 2014). Christmas Island biota are faced with a number of threats, including invasive species and habitat disturbance and/or loss. Many species have small populations and limited distributions, amplifying risks to long-term survival (Director of National Parks, 2014).

Sixty-two percent of the island is national park, protecting mostly virgin forest. Mining lease (1,700 ha) and crown land (3,300 ha) applies to most of the land outside of the national park, including 2,400 ha of primary rainforest. Land-use options for uncommitted crown land (c. 19% of the island) are currently being explored as the island looks to diversify its economy (IORDO, 2018).

Using SCP tools, we identified locations of top biodiversity representativeness and irreplaceability on the island to inform future decisions on land management and use, including on unallocated crown land. We focused on the role that experts (in this case, national park practitioners) had in refining the SCP process through key information inputs. We quantified the influence of three inputs on the final conservation priorities: (1) identification of biodiversity elements for inclusion, (2) refinements to biodiversity models and layers, and (3) inclusion of a landscape condition layer. Our aim was not to evaluate the decisions made, or even the process of arriving at those decisions, but to describe the relative contribution of expert input to the planning process and consider the implications of our observations for conservation planning generally. This supports the development of much needed guidelines for expert consultations during conservation planning.

## 2 | METHODS

### 2.1 | Spatial prioritization process

We used the spatial prioritization tool Zonation (Lehtomäki & Moilanen, 2013) to rank the land areas of Christmas Island according to their biodiversity value, based on the mapped species habitats and other biodiversity components (Table 1). Zonation evaluates the biodiversity value of all sites simultaneously for all components to develop a hierarchical (0–100%) ranking of the region. The top ranked areas maximize the representation of suitable habitat for all included biodiversity components. The spatial prioritization project was undertaken by the authors ("researchers"), in close consultation with Parks Australia ("experts"), the managers of the Christmas Island National Park. The collaborative SCP process consisted of four key steps detailed in Figure 1: (1) collaborative planning and data acquisition, (2) independent analysis, (3) expert review, and (4) final prioritization (Figure 1). Zonation settings for the initial and final prioritization were identical (detailed methods in Supplementary Material S2). Differences between the initial (Step 2, Figure 1) and the final prioritization (Step 4, Figure 1) process, as a result of consultation (Step 3, Figure 1) were:

- Addition of biodiversity layers ($n = 8$)
- Removal of biodiversity layers ($n = 3$)
- Changes to individual biodiversity layers ($n = 11$)
- Addition of a landscape condition layer ($n = 1$)

We conducted individual updated prioritizations ($n = 23$) for each change type implemented after the consultation process and assessed changes between the initial and each updated prioritizations by calculating:

a. the proportion of overlap in the top 10%, 25%, and 50% and bottom 25% and 10% ranked areas;
b. the summed absolute difference in the priority ranking of all grid cells, which gives a value between 0

**TABLE 1** Species and biodiversity components included in the spatial prioritization of Christmas Island. "Difference" describes whether the layer was changed, added, or removed between the initial and final prioritization, and "final map used" indicates the mapping technique used to produce the layer that was used in the final prioritization. "SDM" = species distribution model. Detailed methods for producing SDMs and maps are provided in Supplementary Material S1, Tables S3, changes to biodiversity layers are described in Table S4, and S4 and SDM summary plots in Supplementary Material S7

| Biodiversity layer | Scientific name | Difference | Final map used |
|---|---|---|---|
| Abbott's booby* | *Papasula abbotti* | Changed | SDM of nesting locations |
| CI blue crab* | *Discoplax celeste* | Changed | SDM cropped by maximum known distribution extent. |
| Blue-tailed skink*,+ | *Cryptoblepharus egeriae* | Changed | SDM of species locations |
| Brown booby | *Sula leucogaster* | Added | Point locations of nesting sites with 50 m buffer |
| CI blind snake* | *Ramphotyphlops exocoeti* | Changed | Point locations of observations with 50 m buffer |
| CI emerald dove* | *Chalcophaps indica natalis* | N/A | SDM of species locations |
| CI frigatebird* | *Fregata andrewsi* | N/A | Polygon of colony locations |
| CI goshawk* | *Accipiter hiogaster natalis* | N/A | SDM of species locations |
| CI hawkowl* | *Ninox natalis* | Changed | Density by vegetation type mapped across island (Morcombe, 2016) |
| CI imperial pigeon* | *Ducula whartoni* | N/A | SDM of species locations |
| CI spleenwort* | *Asplenium listeri* | Changed | Point locations with 50 m buffer |
| CI swiftlet* | *Collocalia linchi natalis* | N/A | SDM of species locations |
| CI swiftlet* (breeding caves) | *Collocalia linchi natalis* | N/A | Point locations of caves used for breeding with 100 m buffer |
| CI thrush* | *Turdus poliocephalus erythropleurus* | N/A | SDM of species locations |
| CI white-eye* | *Zosterops natalis* | N/A | SDM of species locations |
| Closed canopy evergreen forest cover | | Added | Percentage cover of trees (>10 m) within 50 m radius |
| CI coastal skink*,^ | *Emoia atrocostata* | Removed | N/A |
| *Cycas rumphii* locations | *Cycas rumphii* | Added | Point locations with 50 m buffer |
| *Cycas rumphii* model | *Cycas rumphii* | Added | SDM of species locations |
| CI flying fox* major roost sites | *Pteporus melanotus natalis* | N/A | Point locations of major colonies with 100 m buffer |
| CI flying fox* foraging habitat | *Pteporus melanotus natalis* | Added | SDM of species foraging locations (night) |
| CI flying fox* roosting habitat | *Pteporus melanotus natalis* | Changed | SDM of species roosting locations (day) |
| CI forest skink*,^ | *Emoia nativitatis* | Removed | N/A |
| CI giant gecko* | *Cyrtodactylus sadleiri* | Changed | SDM of species locations |
| Golden bosun* | *Phaethon lepturus fulvus* | N/A | Interpolated reporting rates across island |
| Lister's gecko*,+ | *Lepidodactylus listeri* | N/A | SDM of species locations |
| Mangrove species | *Bruguiera gymnorhiza & B. sexangula* | Changed | Polygons of species extent |
| *Pneumatopteris truncata** | *Pneumatopteris truncata* | N/A | Point locations with 50 m buffer |
| Rare plant species locations* | Multiple species | Added | Point locations with 50 m buffer |
| CI red crab* | *Gecarcoidea natalis* | Changed | SDM of burrow locations |
| Red footed booby | *Sula sula* | Added | SDM of species locations |
| Robber crab | *Birgus latro* | Removed | N/A |

*(Continued)*

**TABLE 1** Continued

| Biodiversity layer | Scientific name | Difference | Final map used |
|---|---|---|---|
| *Tectaria devexa* subsp. *minor*—habitat suitability | *Tectaria devexa* | N/A | SDM of species locations |
| *Tectaria devexa* subsp. *minor*—population locations | *Tectaria devexa* | Changed | Buffered 50 m point locations weighted by population size |
| Wet refuges | N/A | Added | Polygons of persistently wet areas |

CI = "Christmas Island."
*Endemic to CI.
+Extinct in wild (captive population).
^Believed extinct.

(identical solution) and 1 (mirror image solutions) (Kujala et al., 2018b); and

c. Spearman's correlation coefficient ($r$).

We mapped changes between initial and final prioritizations by subtracting the final cell ranking from the initial cell ranking. Species level impacts of the consultation process were quantified by measuring the proportion of the island-wide distribution of each biodiversity component represented in the top 10% and bottom 10% in initial and final prioritizations. We used the final set of biodiversity layers for this process.

## 2.2 | Biodiversity data

Data on species occurrences and habitat were provided by Parks Australia from their long-term monitoring program (Director of National Parks, 2013) and other databases (Step 1, Figure 1). The researchers' initial selection of species for inclusion in the spatial prioritization (Step 2, Figure 1) was based on the draft Christmas Island Biodiversity Conservation Plan (Director of National Parks, 2014), which identifies 26 species considered "significant" to the island, following their listing status, ecological role or community importance (species listed as extinct were excluded). During the consultation process, eight additional biodiversity components were identified as important to represent in the SCP process (Table 1). Two species in the initial set were removed because they have not been observed for many years and are thought to be extinct, and one was removed because the data collected was not considered representative due to difficulties detecting the species (Table 1).

For species with both presence and absence information, we modeled distributions using boosted regression trees (Ridgeway, 2017). We used *Maxent* for species with presence data only (Jurka, 2012). Detailed modeling methods are provided in Supplementary Material S1 and S3. Distribution maps for species with <20 data points were compiled from the point observation locations with a 50 m buffer, while point locations of critical habitats were given a buffer of 100 m (Table 1, Table S2). Biodiversity components with restricted and distinct distributions were mapped with polygons or relevant measurements. In the consultation process changes to some biodiversity layers were made, based mainly on (a) advice on most representative and reliable dataset or data source (where >1 option available), (b) newly available data, (c) predictors considered relevant or irrelevant to species biology, and (d) modification of modeled distributions to reflect the known distribution limits of the species (Table S4). Biodiversity layers included in the final prioritization are presented in Supplementary Material S6.

## 2.3 | Condition layer

The consultation process revealed that while the biodiversity layers were considered broadly representative of species distributions across the island, fine-scale contrasts in species occurrence between primary and secondary vegetation were not adequately reflected. Restoration of native vegetation, especially where surface soil has been removed, often fails to reinstate original biodiversity and ecosystem processes (Curran, Hellweg, & Beck, 2014). Consequently, a landscape condition layer was developed and applied in the final spatial prioritization. Areas on the island that had not been previously cleared were given a condition rating of one, while condition ratings in areas that had been previously cleared (c. 25% study area) were rated <1 according to their level of disturbance and rehabilitation, based on LIDAR measurements of canopy height. Detailed methods for developing the condition layer are provided in Supplementary Material S2. The condition layer, containing values between 0 and 1, was used to multiply all biodiversity input layers.

# 3 | RESULTS

The final spatial prioritization highlighted a number of important areas distributed across Christmas Island (Figure 1). The highest ranked areas were mostly located on the western coast and southwest point, the eastern end of the north coast, and the central-east coast. The lowest ranked areas (bottom 10%, black areas in Figure 1) were located inland in the north east

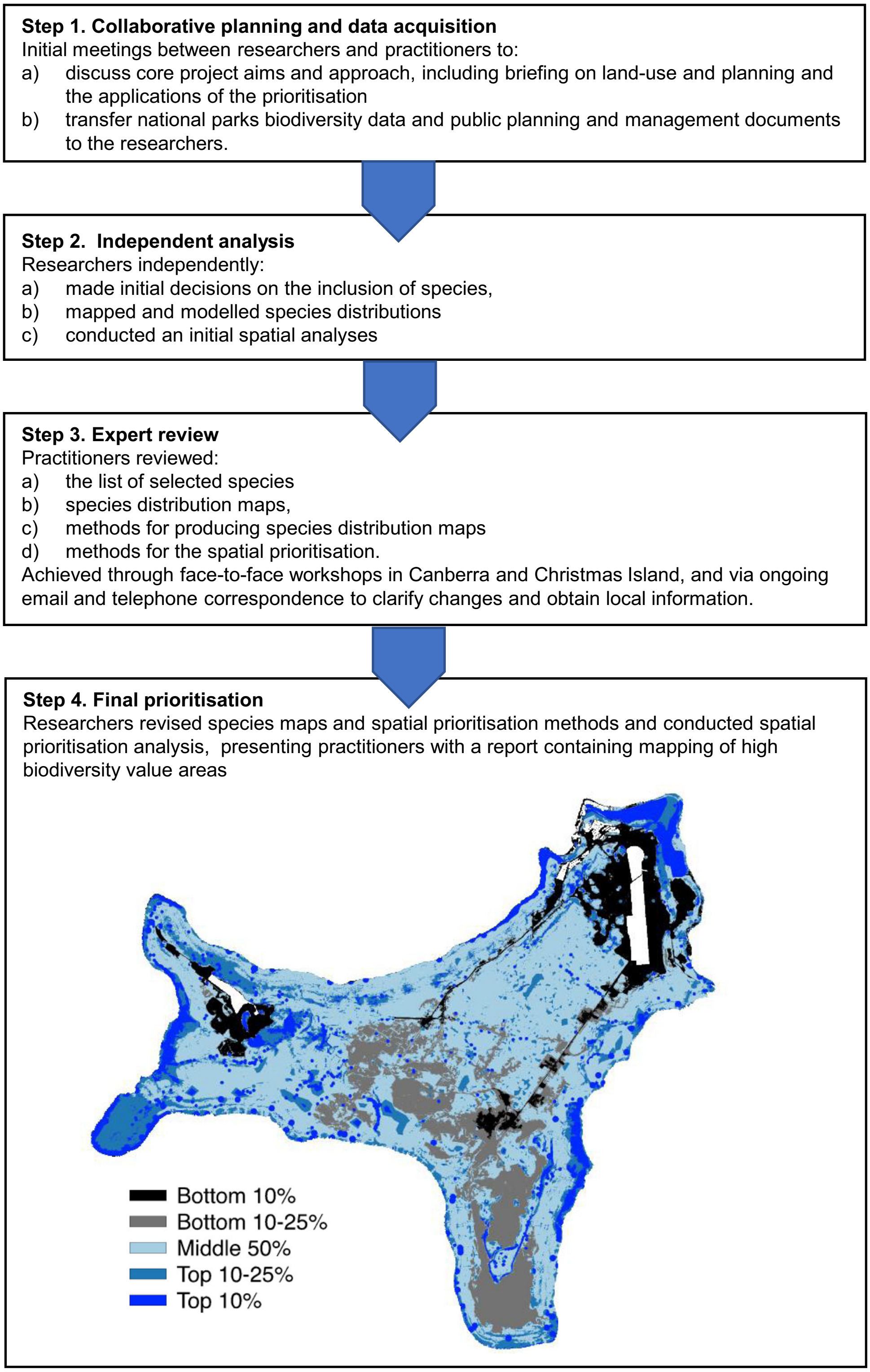


**FIGURE 1** Process chart documenting the steps in the collaborative spatial prioritization process for Christmas Island and the resulting final prioritization map of Christmas Island, documenting the hierarchical ranking of the island ranging from the lowest conservation priorities (bottom 10% ranked area of the island, black) to the highest (top ranked 10% of the island, bright blue). The top ranked areas maximize the representation of suitable habitat for all included biodiversity components (Table 1). Further details on the format of the consultation process (Steps 1 and 3) are provided in Supplementary Material S8

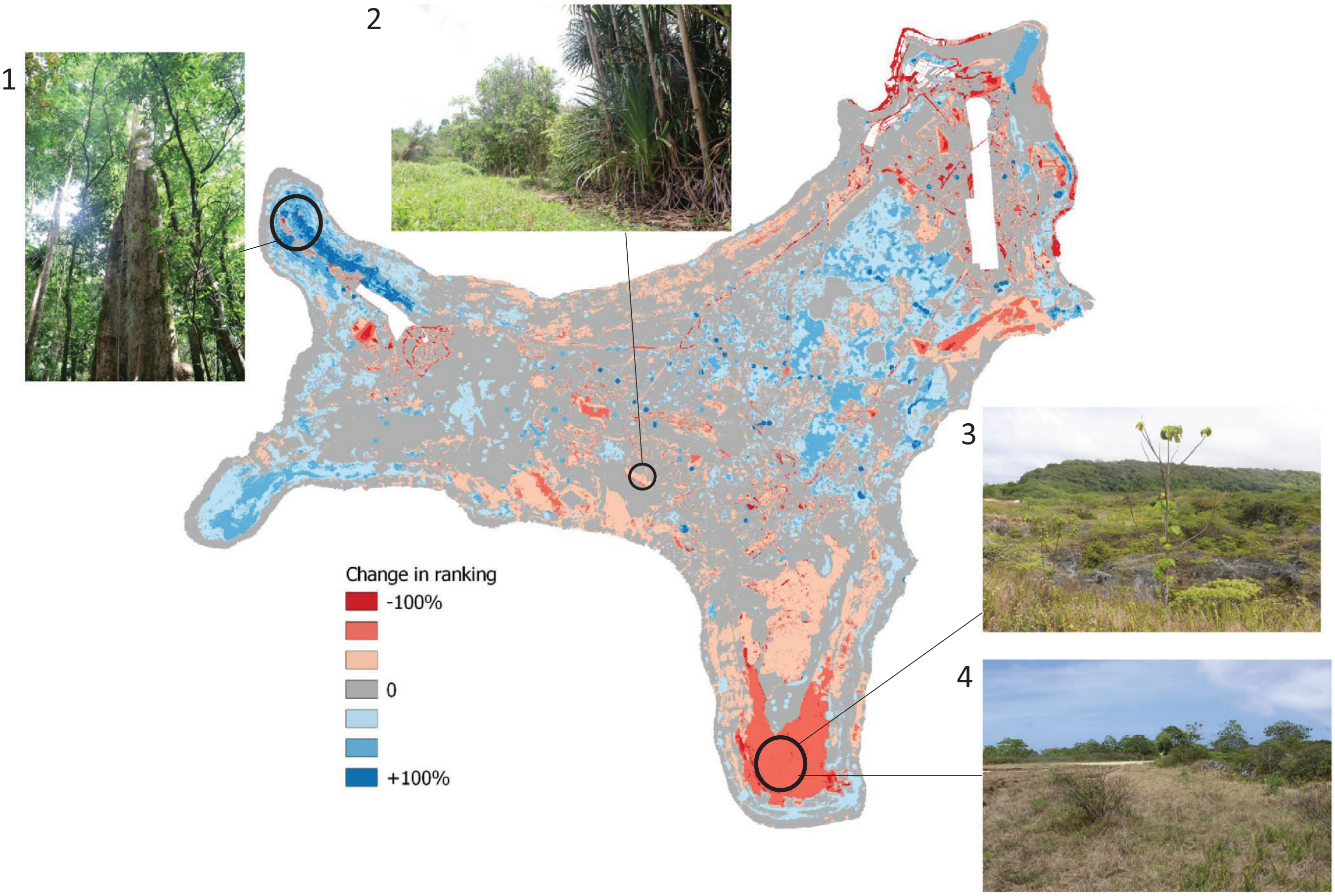


**FIGURE 2** Change in spatial prioritization rankings of Christmas Island before and after expert consultation. Locations in red are those that shifted down most substantially (e.g., from top 1% to bottom 1%), locations in blue are those that shifted up most substantially (e.g., from bottom 1% to top 1%). Photos are examples of locations that shifted substantially: (1) a patch of closed canopy evergreen forest, (2) a previously mined area consisting of un-rehabilitated fern-field (left side of photo and dark red within highlighted circle on map) and area with thin topsoil that has been rehabilitated with low vegetation (right side of photo and pale red color within circle), (3, 4) previously mined areas that have not been rehabilitated

and inland at northwest point around currently developed and populated parts of the island.

The final prioritization reflected a changed distribution of conservation priorities, with $r = 0.57$ between the initial and final solutions, and an absolute difference in cell ranking (hereafter, "cell ranking change") of 8.92% (Figure 2). Inclusion of the condition layer made the largest individual change to the initial prioritization solution, resulting in a cell ranking change of 6.10% and $r = 0.77$ with the initial solution. Removal of species ($n = 3$) had very little influence on cell rankings (mean cell ranking change = 0.14%; range 0.01–0.41%) and mean $r$ was near unity for each species layer removed. Changes to individual species layers ($n = 11$) resulted in relatively low changes in rankings (mean cell ranking change for each changed layer = 0.61%, range 0.01–2.05%), and $r$ was near unity in each case (Figure 3b). Additional species ($n = 8$) on average resulted in cell ranking changes of 1.02% (0.05–3.08%) for each species added (mean $r = 0.97$).

There was lower overlap in bottom ranked areas than top ranked areas when comparing the initial prioritization with updated solutions (Figure 3a). The top 10% and 25% areas overlapped by 58% and 68%, respectively, when comparing initial and final prioritizations, while the bottom 25% and 10% areas overlapped by 45% and 51% (Figure 3a). This pattern was more pronounced with the effect of the condition layer, with a 91% (top 10%) and 89% (top 25%) overlap in top ranked areas between the initial solution and the addition of the condition layer, compared with 51% (bottom 25%) and 44% (bottom 10%) overlap in the bottom ranked areas.

Locations of *Cycas rumphii*, rare plants, wet refuges and brown booby habitat had better representation in top ranked areas after these components were added to the prioritization process. For these components the proportion of distribution captured within top ranked areas increased by between 52% and 79% in the final prioritization (Figure 4a). There was little difference between the initial and final prioritization when the other four layers were added (Figure 4a).

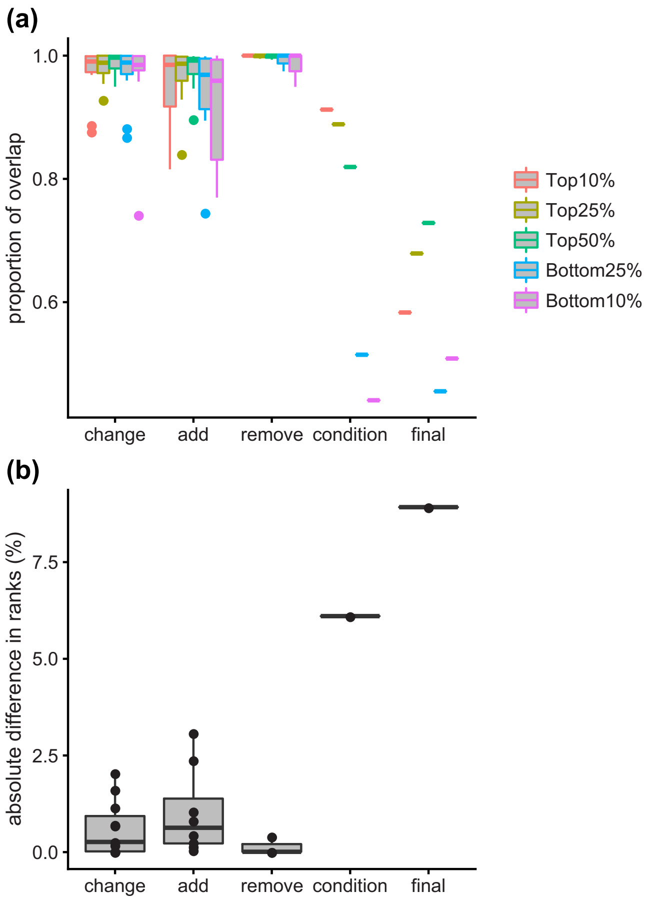


**FIGURE 3** Quantification of the changes to the initial spatial prioritization due to each individual change made to the prioritization process after expert consultation. Changes are grouped in boxplots according to the type of change made: (1) biodiversity layer changed ("change," $n = 11$), (2) addition of biodiversity layer ("add," $n = 8$) (3) removal of biodiversity layer ("remove," $n = 3$), (4) application of condition layer ("condition," $n = 1$); and (4) the cumulative difference between the initial and final prioritization, with all changes applied concurrently ("final"). "A" documents the percentage overlap between the initial and updated prioritization of areas ranked in the top 10%, top 25%, top 50%, bottom 25%, and bottom 10% of the island; "B" documents the summed absolute difference in the priority ranking of all grid cells, as a percentage ranging from 0 (identical solution) and 100% (mirror image solution)

For most species, modifications to maps or models had little influence on their representation in the top 10% ranked areas (Figure 4b). Exceptions were the rare CI blind snake and *Asplenium listeri*, which had some point locations missing from the initial prioritization, and the CI blue-crab, whose extent of distribution had been over-estimated in the modeling process (Table S2). There was little difference to the representation of species whose maps remained unchanged after consultation (Figure 4c). The bottom 10% rankings in the initial and final prioritization represented similar proportions of mapped habitat for most species, with small (1–5%) shifts up or down between the initial and final prioritization solution for all species except for *Cycas rumphii* locations, which shifted from 24% to 1% (Figure S1).

## 4 | DISCUSSION

Our results quantify, in a real conservation planning case study, the important contribution that expert knowledge and data can make to the outcomes of spatial conservation prioritization. There was just 0.57 correlation between the spatial conservation priorities on Christmas Island before and after expert consultation, indicating that local ecological knowledge can play an important role in determining where conservation priorities are located.

The most significant individual change made in the consultation process was the inclusion of a landscape condition layer, resulting in an average cell ranking change of 6% and substantial changes in the location of the bottom ranked areas (Figure 3). This is in line with earlier findings that costs, condition, or threat layers can influence conservation prioritization solutions much more than single biodiversity layers (Armsworth et al., 2017; Ferraro, 2003; Kujala, Lahoz-Monfort, Elith, & Moilanen, 2018a). Given their large influence, it is critical that the accuracy and influence of these layers be considered carefully in SCP projects. The Christmas Island condition layer was compiled using high resolution data (2 m) on vegetation height and applied to an area of previously cleared vegetation (c. 25% of Christmas Island). The lowest (10%) ranked areas were most highly affected by the application of the condition layer, however in both the initial and final solutions these bottom ranked areas represented very low proportions of habitat for most biodiversity components (5.5% and 4.2% respectively, Figure S1), and so the inclusion of the condition layer seems to have shifted rankings toward higher quality vegetation without compromising (mapped) representation of species (Figure 2).

Although individual addition, removal or modification of biodiversity layers had little influence on the overall distribution of spatial priorities (Figure 3), in combination they caused a 0.2 reduction in similarity between the initial and final solution. Adding new species layers, or modifying existing layers made little difference to the representation of species whose layers remained unchanged (Figure 4a), indicating that there were low costs to the representation of these unchanged species by adding new species or improving information for other species. However, there were important species-level effects for the additional species themselves. Species with relatively restricted distributions (Supplementary Material S6) were poorly represented in top ranked areas until they were explicitly included in the prioritization (*Cycas rumphii,* rare plants, brown bobby and wet refuges). This supports recent findings that biodiversity elements with restricted distributions are one of the more influential elements of SCP

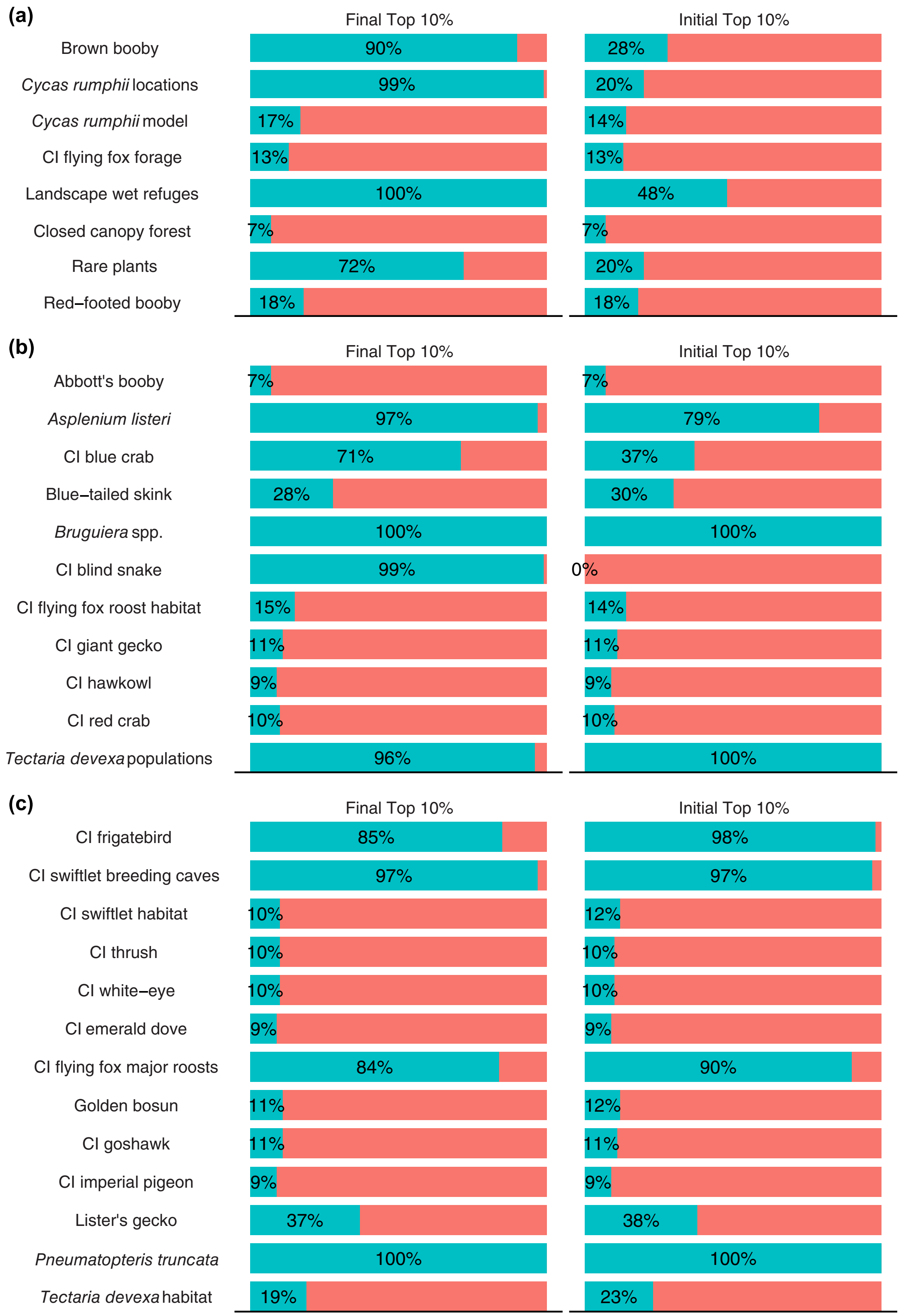


**FIGURE 4** Proportion of species distributions/biodiversity components (biodiversity layers, Table 1) represented in the top 10% ranked areas in the final prioritization compared to the initial prioritization for (a) species that were added to the prioritization (i.e., layers included in the final but not initial prioritization), (b) species with layers that changed between the initial and final prioritization, and (c) species included in both initial and final prioritization with no changes made to layers. Representation of species in each scenario was measured using the final distribution maps for each species. “CI” = Christmas Island

exercises (Kujala et al., 2018b), and so deserve to be a central focus in SCP refinements and consultations. Fine-tuning maps and modeling approaches for more widespread species appears to be less important to spatial prioritization outcomes.

Locations of the bottom priority rankings were most sensitive to the changes implemented from the consultation process—especially when it came to the inclusion of the landscape condition layer. Decisions informed by the location of land considered least valuable for biodiversity, such as where to develop, may be more sensitive to improvements in information than decisions on which areas to conserve (Kujala et al., 2018b). Our findings show that failure to include expert input could result in unknown or unnecessary biodiversity losses. For example, if the initial bottom 10% ranked area of Christmas Island were to be developed, the rare cycad *Cycas rumphii* would have lost one quarter of its known population if spatial prioritization was conducted without expert consultation (which lead to the species inclusion).

In this study, the expert input came from national park practitioners. Practitioners may distrust conservation recommendations from models that are developed in the absence of consultation (Southwell, Tingley, Bode, Nicholson, & Phillips, 2017), so a major benefit of collaborative conservation planning is an improved likelihood of implementation (Knight et al., 2006). Our findings show that expert input from practitioners also improved the model outputs, in particular by increasing representation of rare species. Expert consultation should be explicitly recognized as a critical element of spatial conservation prioritization processes. To that end, explicit protocols should be developed to ensure we get the best out of expert input to SCP projects.

Our results show how different information inputs have notably different impacts on the final plan—understanding these differences helps plan time and resources for expert consultation. Having the largest impact on the SCP solution, development and inclusion of landscape condition layers deserves particular attention, as does the mapping and inclusion of rare species. On the other hand, fine-tuning maps and modeling approaches for more widespread species may not be an efficient use of time. Methods for improving the accuracy and reducing the bias of expert-elicited information have seen rapid development (Hemming, Burgman, Hanea, McBride, & Wintle, 2018), and we suggest that these structured protocols could be customized and applied to SCP. In this study, we had excellent spatial data on species occurrences, vegetation cover, and environmental variables. Structured protocols for engaging with and eliciting knowledge from practitioners would be particularly valuable in situations where there is a larger degree of uncertainty in data, because it is likely that these situations would lead to much greater sensitivity to practitioner input and potential for biased outcomes. Finally, we suggest that the focus of consultations and collaborations should always be on the SCP information inputs, and should not be biased toward achieving any particular spatial outcome.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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